

A COMPARATIVE STUDY ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A356-B₄C AND A356-GRAPHITE COMPOSITES

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ABSTRACT

This work investigated the influence of boron carbide and graphite on the microstructure and mechanical behavior of A356-B₄C and A356-Graphite composites. The investigation reveals the effectiveness of incorporation of B₄C and Graphite in the A356 alloy for studying mechanical properties. The composites were fabricated using liquid metallurgy route. The A356- B₄C and A356-Graphite composites were fabricated separately by introducing 4 wt. % of B₄C and graphite particulates. The characterization was performed through Scanning Electron Microscope and Energy Dispersive Spectrum. The particle distribution was uniform in these composites. The density, hardness, ultimate tensile strength, yield strength and percentage elongation of both B₄C and Graphite composites were evaluated. Further, a comparative study has been made between the A356- B₄C and A356-Graphite composites. The B₄C and graphite addition in the Al matrix proved to account for the dramatic change of the fracture mechanism of composites.

KEYWORDS: A356 alloy; B₄C; Graphite; Mechanical Properties & Microstructure

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INTRODUCTION

Metal matrix composites (MMCs) offer designers requirements, they are particularly suited for applications requiring high strength to weight ratio at high temperature, good structural rigidity, dimensional stability, and light weight. The inadequacy of metals and alloys in providing both strength and stiffness to a structure has led to the development of various composites particularly metal matrix composites (MMCs) [1, 2]. Composite materials are used extensively as their higher specific properties (properties per unit weight) of strength and stiffness, when compared to metals, offer interesting opportunities for new product design. MMCs are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix [3, 4]. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, etc. The particle distribution plays a very vital role in the properties of the Al MMC and is improved by intensive shearing [5].

Addition of hard ceramic particles like SiO_3 , SiC , Al_2O_3 , TiB_2 , B_4C etc. to Al matrix lead to strengthening of the matrix with improved properties [6]. Ceramic particles such as Al_2O_3 and SiC are the most widely used materials for reinforcement with aluminum. Boron carbide (B_4C) could be an alternative to SiC and Al_2O_3 due to its high hardness (the third hardest material after diamond and boron nitride) [7]. B_4C has attractive properties like high strength, low density, extremely high hardness, good wear resistance and good chemical stability. Hence reinforcing the aluminum with B_4C particles confers high specific strength, elastic modulus, good wear resistance and thermal stability [8]. From the Literature survey it can be concluded that, most of the studies on aluminum based MMCs are devoted to SiC and Al_2O_3 particulate reinforcements; however, use of TiC particulates as reinforcements in aluminum matrix is relatively limited.

Although powder metallurgy produces better mechanical properties in MMCs, liquid state processing has some important advantages. They are as: better matrix-particle bonding, easier control of matrix structure, simplicity, low cost of processing, nearer net shape and the wide selection of materials. Liquid state fabrication of MMCs includes two methods which depend on the temperature at which the particles are introduced into the melt. In melt stirring process, the particles are incorporated above the liquidus temperature of the molten alloy, while in compo-casting method the particles are incorporated at the semi-solid slurry temperature of the alloy. In both processes, the vortex is used for introducing reinforcement particles.

Micro particulates are very economical, because of their low prices and easy dispersion during fabrication. The micron particle reinforced Al matrix composites own the potential commercial use for its relatively low cost and good mechanical properties. Micron particle reinforced metal matrix composite is usually produced by powder metallurgy, high energy ball milling, sputtering and stir casting. Among all of these methods, stir casting is regarded as the most productive and economical. However, this method has always been accompanied by the formation of lots of structural defects in composite materials. Poor wettability and non uniform distribution of reinforcing particles, segregation and agglomeration of the reinforcement particles in the matrix, weak matrix reinforcement interface and presence of porosity are some important structural defects of stir casted composites [9].

In the present work, an investigation has been made to study the microstructure and mechanical properties of A356-4 wt. % of B_4C and A356-4 wt. % of Graphite composites fabricated by stir casting process. Here, composites are produced by two stage particles mixing process to enhance the wetting behaviour and also to achieve the better bonding between the A356 alloy matrix and B_4C -Graphite particulates.

MATERIALS AND METHODS

Materials

Table 1: Chemical Composition of A356 Alloy

Element	Element
Magnesium	0.29
Silicon	7.20
Iron	0.18
Copper	0.02
Zinc	0.01
Manganese	0.01
Titanium	0.11
Nickel	0.01
Aluminium	Bal

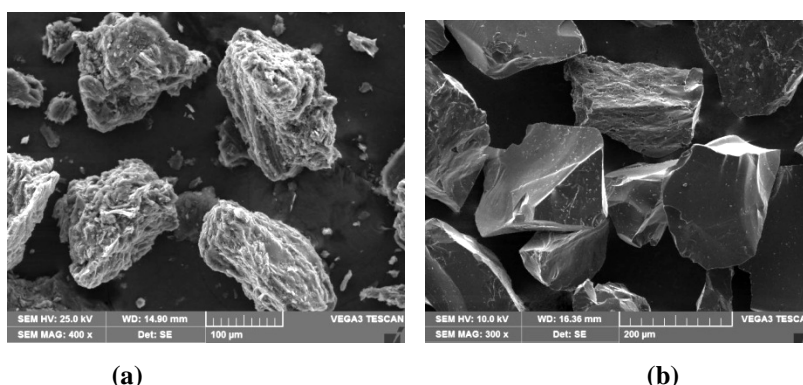


Figure 1: Showing the Scanning Electron Microphotographs of (a) B₄C (b) Graphite Particles

In the present study, A356 alloy with the theoretical density of 2700 kg/m³ was used as a matrix material. The chemical composition of the matrix material is given in Table 1. B₄C with theoretical density of 2520 kg/m³ and graphite particles with 2200 kg/m³ were used as reinforcements. Figure 1 shows the B₄C and graphite particles of size 80-100 microns used in the study.

Preparation of Composites

Initially B₄C and graphite particulates were preheated for 500°C. In the present work, an attempt has been made to study the mechanical properties of as cast A356 alloy, A356-B₄C and Al356-Graphite particulate composites. The composites containing 4 wt. % of B₄C and 4 wt. % of Graphite particulates were prepared. Initially required amount of charge or matrix material was placed in a graphite crucible, which was placed in electric resistance furnace at a temperature of around 730 degree Celsius. After complete melting of A356 alloy matrix, degassing was carried out by using Solid Hexa Chloroethane [10], which helps to remove unwanted adsorbed gases from the melt. Once degassing is over, the preheated ceramic B₄C reinforcement particles were introduced into matrix in a novel way which involves two-stage additions of reinforcement during melt stirring [11]. A continuous stirring process was carried out during addition of reinforcement into matrix. Normally for all composite preparation, stirring speed was maintained at 300rpm. After 5 minutes of continuous stirring, entire molten metal was poured into cast iron die. Similarly, A356-Graphite composites were prepared by same route. The prepared composites were machined and tested for micro structural studies. The composites revealed uniform distribution of B₄C and graphite particles in the matrix, tensile behaviour of as cast A356 alloy and its composites were evaluated as per ASTM standards.

Testing of Prepared Specimens

The metallographic specimens were prepared through standard procedure of mechanical polishing followed by etching with a Keller's chemical solution, which is commonly used for Al alloys and its composites. The particle distribution in the A356 alloy matrix at various fabrication conditions were examined by scanning electron microscope coupled with an energy dispersive X-ray spectroscopy (EDS).

The experimental density of un-reinforced A356 alloy, A356-B₄C and A356-graphite composites were measured by dividing the measured weight of test sample by its measured volume using an electronic weighing machine. The theoretical density of the composite was calculated by rule of mixture using formula:

$$\rho_{th} = \rho_m V_m + \rho_r V_r \quad (1)$$

Where ρ_m is the density of matrix, V_m is the volume fraction of the matrix, ρ_r is the density of reinforcement and V_r is the volume fraction of the reinforcement.

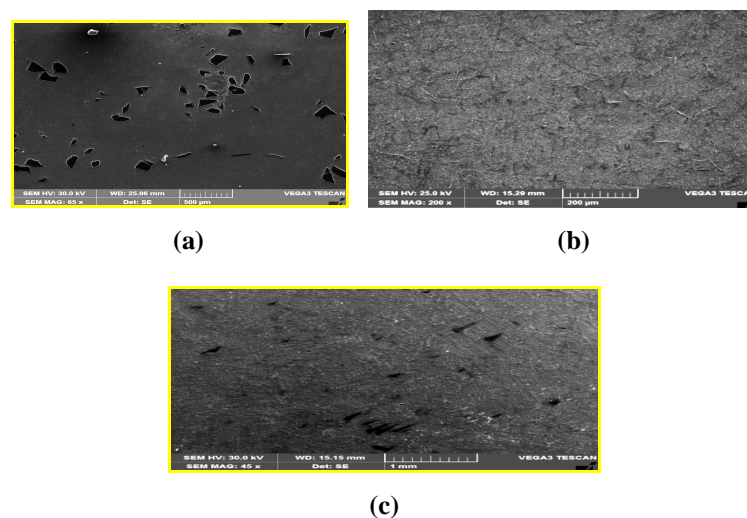
Indentation response of as cast Al matrix alloy and its micro composites were evaluated by Brinell hardness tester. The required specimens were prepared according to standard metallographic procedures. The experiments were carried out by applying a load of 250kgf and dwell time of 30 seconds. The indentation load depth values were recorded and the hardness was determined. For each sample, the indentation test was repeated 3 times and the averaged data were reported.

Tensile testing of the prepared samples were conducted in accordance with the ASTM E8 standard on round tension test specimens of gauge diameter 9mm and gauge length 45mm. Tension test was conducted by using Instron made servo-hydraulic machine, with cross head speed set at 0.280mm/min. The experiments were conducted at room temperature. Stress versus strain graph was plotted to know the effect of B_4C and Graphite particulates on tensile behavior of A356 alloy composites. Further, from the graph ultimate tensile strength, yield strength and percentage elongation were recorded and comparison made.

RESULTS AND DISCUSSIONS

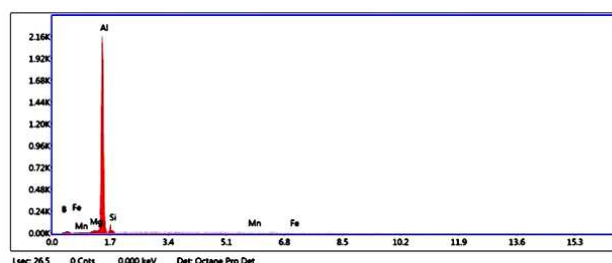
Microstructural Studies

Figure. 2 a-c shows microstructure of as cast A356, A356-4 wt. % B_4C and A356-4 wt. % graphite composites. Generally the matrix systems in aluminium base alloy cast particulate include, Al-Si, Al-Cu or Al-Zn-Mg alloys which have eutectic type phase diagrams. The hypoeutectic, eutectic and hypereutectic Al-Si base alloys are frequently used as matrices for particulate reinforcements including graphite, alumina and silicon carbide. The possible interfaces in these Al-Si matrix alloy systems can be between the primary α -aluminium and reinforcement, or between primary silicon and reinforcement, or between the eutectic of aluminium-silicon and the reinforcement [12]. Figure 2b and 2c revealed that there is fairly uniform distribution of B_4C and graphite particulates throughout the matrix alloy. It is also observed that porosity is lower. Further, from the SEM micrographs, it can be seen that there is good bonding between the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforcement material [13].

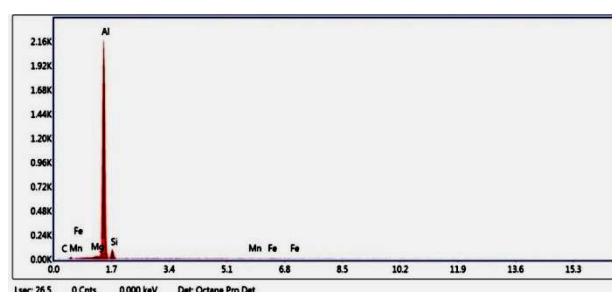


**Figure 2: Showing Scanning Electron Microphotographs of (a) as Cast A356 Alloy
(b) A356-4 wt. % of B_4C (c) A356-4 wt. % of Graphite Composites**

Figure 3 a-b are energy dispersive X-Ray spectrographs of A356-4wt. % of B₄C and A356-4 wt. % of graphite composites respectively. The EDS analysis confirmed the presence of B₄C and Graphite in the Al matrix alloy. The presence of B₄C and graphite shows in the form of Boron (B) and Carbon (C), which is evident from the EDS graph 3a and b.



(a)



(b)

Figure 3: Showing the Energy Dispersive Spectrographs of (a) A356-4 wt. % B₄C (b) A356-4 wt. % Graphite composites

Density Measurements

Figure 4 shows the results of theoretical and experimental densities of the composite samples fabricated by two stages melt stirring. This section also presents the comparison of theoretical density obtained by rule of mixture and measured density values by experimentation for the composite studied. Figure 4 shows the experimental and theoretical densities values of the composites containing 4 wt. % percentages B₄C and graphite. From Figure 4, it can be concluded that the experimental and theoretical densities are in line with each other and confirm the suitability of the liquid metallurgy technique for the successful composite preparation. Further, it can be observed that the density of A356-B₄C and Graphite composites are lower than that of the base matrix, it is mainly due to density of B₄C (2.52 g/cm³) and Graphite (2.20 g/cm³) particulates is lower than the base matrix Al356 alloy (2.71 g/cm³).

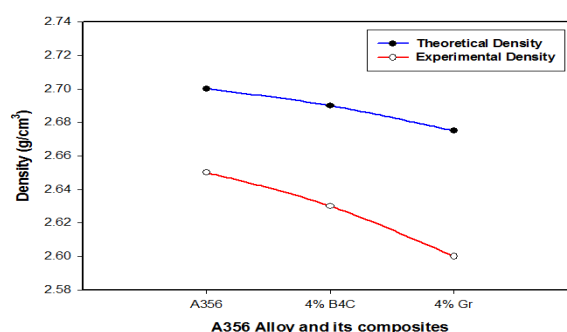


Figure 4: Theoretical and Experimental Densities of A356 Alloy and its Composites

Hardness Measurements

The hardness of as cast A356, A356-B₄C and A356-graphite composites containing 4 wt. % of B₄C and Graphite are evaluated using ball indenter at an applied load of 250 kgf with dwell time 30 seconds for each sample at different locations. The hardness variation of samples with the B₄C and graphite wt. % is illustrated in Figure 5. The hardness of A356- B₄C composites (82.2 BHN) is higher than the A356 base alloy, due to presence of B₄C particles. Also, it can be attributed to the higher hardness of B₄C particles compared to aluminium alloy. In fact, the hardness of composite depends on the hardness of the reinforcement and the matrix. This increase in hardness is mainly due the coefficient of thermal expansion (CTE) of ceramic particles is less than that of aluminium alloy [14]. So, enormous amount of dislocations are generated at the particle-matrix interface during solidification process, which further increases the matrix hardness. The higher the amount of particle-matrix interface, the more is the hardening due to dislocations.

Further, the hardness of A356-graphite composites is lesser than the base matrix. This decrease in hardness is to be expected since graphite, being a soft dispersoid, does not contribute positively to the hardness of the composite [15]. The graphite being an effective solid lubricant renders the material more easily deformable with respect to the indenter of the hardness tester.

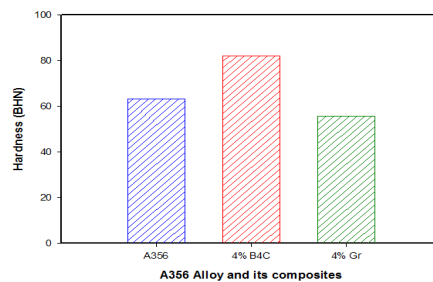


Figure 5: Hardness of A356 Alloy and its Composites

Tensile Properties

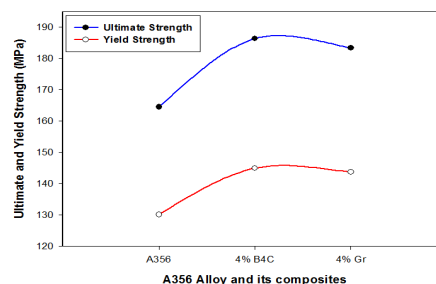


Figure 6: Ultimate and Yield Strength of A356 and its Composites

The tensile behaviour of all the prepared samples of composites is determined to examine the tensile properties like ultimate tensile strength and yield strength. The specimens were loaded hydraulically in the computerized universal testing machine. The loads at which the specimen has reached the yield point and broken were recorded. The effect of B₄C and graphite particles addition on the ultimate tensile strength and yield strength of the samples is shown in figure 6. In brief, the strengthening is a result of two major contributions, indirect strengthening and direct strengthening [16]. The ultimate tensile strength and yield strength shows an improvement with the content of B₄C and Graphite, which is mainly the result of increasing dislocations density and their pile-ups behind the uniform distributed B₄C and Graphite

particles. Indirect strengthening results from the changes in the matrix microstructure that takes place due to the presence of reinforcement particles. In the Al- B₄C composites, indirect strengthening arises from an increase in dislocation density due to the coefficient of thermal expansion mismatch between B₄C and A356 alloy. The density of these thermally induced dislocations also increases with increasing weight fraction of B₄C, so the indirect strengthening contribution increases with increasing B₄C content. On other hand, this gradual enhancement seems to be due to work hardening behavior. Further, A356-4wt. % of graphite composites are showing more ultimate tensile strength and yield strength compared to A356 alloy. This increase in strength is mainly due to an increase in percentage elongation in the case of graphite composites, makes the material to take more load before fracture.

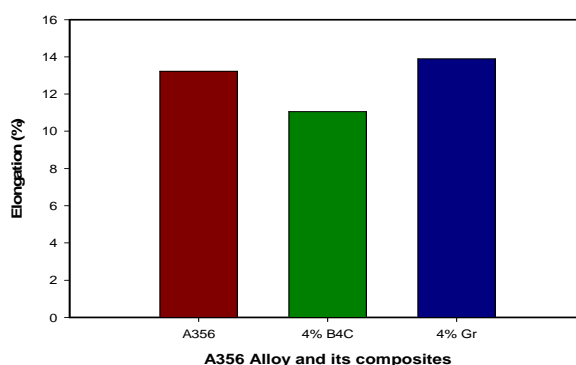


Figure 7: Percentage Elongation of A356 and its Composites

Figure 7 reveals the presence of hard reinforced particles such as B₄C in the metal matrix reduces the percentage of elongation during tensile testing as the brittleness of the metal increases. Figure 7 is a graph showing the effect of graphite content on the ductility of the Al alloy composite. It can be seen that as the graphite content increases, the ductility of the composite material increases by significant amount.

CONCLUSIONS

The present work entitled, “A comparative study on microstructure and mechanical properties of A356-B₄C and A356-Graphite composites” has led to the following conclusions:

- A356-B₄C and A356-Graphite composites with 4 wt. % were successfully fabricated via melt stirring method involving two step additions.
- Two stage addition methods is adopted for introducing B₄C and Graphite particulates into A356 matrix during melt stirring has resulted in homogeneous distribution of B₄C and Graphite particulates with no clustering or agglomeration as evident from SEM microphotographs.
- The Energy Dispersive (EDS) analysis revealed the presence of B₄C and Graphite particles in A356- B₄C- Graphite composites.
- The density of A356-B₄C-Graphite composite has decreased after the addition of B₄C and Graphite particulates into aluminium matrix could be due to formation of small amount of pores and low density of B₄C and Graphite particulates when compared to the density of A356 might be contributing to the decrease in overall density of the composite.

- A356- B₄C composites have shown higher hardness when compared to the hardness of A356 alloy.
- The hardness of A356-Graphite composites decreases with 4 wt.% of Graphite particulates in the A356 alloy matrix.
- Improvements in ultimate tensile strength of the A356 matrix were obtained with the addition of B₄C particulates. The extent of improvement obtained in A356 alloy after addition 4 wt. % of B₄C particulates was 13.3% .
- Improvements in ultimate tensile strength of the A356 matrix were obtained with the addition of Graphite particulates. The extent of improvement obtained in A356 alloy after addition 4wt. % of Graphite particulates was 11.4%.

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